Nato Advance Research Workshop

THE GLOBAL GEOMETRY OF TURBULENCE: *Impact of nonlinear dynamics*

Rota (Cádiz), SPAIN. 8-14 July 1990

Abstracts and Technical Programme

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The Global Geometry of Turbulence

Impact of nonlinear Dynamics

Rota (Spain) July 8-14, 1990

TECHNICAL PROGRAMME

Sunday, July 8

18.00-20.00 ARRIVAL OF PARTICIPANTS AND REGISTRATION

Monday, July 9

9.00-9.15 OPENING REMARKS

9.15-12.15 AMPLITUDE EQUATIONS
Chairman: *Ahlers*

P. Huerre *Lab. Meteorologie Dynamique, Ec. Politechnique, Paris, France*
Amplitude equations and stability. *(Invited)*

Roberto Benzi *Fisica, Universita di Roma, Italy*
Stochastic perturbations on amplitude equations

S. Fauve *Physics, ENS Lyon, France*
Localised structures generated by subcritical instabilities

J.D. Gibbon *Mathematics, Imperial Coll., London, U.K.*
The ladder method and the prediction of turbulence in 2-D CGL eqs.

J. Jiménez *Dept. Fluid Mech., Aeronautics, U.P. Madrid, Spain*
Solitary solutions of non-symmetric amplitude equations

16.00-18:45 SHEAR FLOWS, I
Chairman: *Wygnanski*

E. Hopfinger, J.-M. Chomaz & P. Bonneton *Inst. Méchanique Grenoble, France*
Interaction of turbulent wake and internal gravity waves

M. Gharib, M. Beizaie & D. Liepmann *AMES, UC San Diego, Ca. USA*
Experiments in 2-D Turbulence

D. Papailiou *Mechanical Engineering, U. Patras, Greece*
Dynamics of Large scale structures in turbulent two dimensional jets

E. Roesch, F.Ohle, H.Eckelmann & A.Huebler *Max-Planck Inst. Stromungsf., Göttingen, Germany*
Modelling and control of Kármán vortex streets

K.R. Sreenivasan *Eng. Applied Science, Yale U., New Haven, Conn. USA*
Fractals and Multifractals in turbulence

20:00-22.00 WELCOME PARTY

Tuesday, July 10

9.00-13.00 BIFURCATIONS AND TRANSITION TO CHAOS
Chairman: *Pérez García*

Y. Pomeau *Phys. Statistique, ENS, Paris, France*
Bifurcations and Subcritical Instabilities. *(Invited)*

J.C. Antoranz *Dept. Física Fundamental, UNED, Madrid, Spain*
Transition to Chaos in Nonlinear Oscillators

H. Chaté & P. Manneville *Inst. Recherche Fondamentale, CEN-Saclay, France*
Spatiotemporal intermittency in the one dimensional complex Ginzburg Landau equation

J-M. Chomaz *CNMR, Toulouse, France*
Global Mode Resonances in Open Flows

M.A. Rubio *Dept. Física Fundamental, UNED, Madrid, Spain*
Instabilities in streams with moving contact lines

C.W. Van Atta *Dept. AMES, UC San Diego, Ca. USA*
Fluid dynamical chaos in vortex wakes

M.G. Velarde *UNED-Ciencias, Madrid, Spain*
Instabilities, waves and solitons excited by capillarity and interfacial stresses

16.00-19:30 DIRECT NUMERICAL SIMULATION
Chairman: *Zabusky*

P. Moin *Mechanical Eng., Stanford U., Ca. USA*
What can we learn from Direct Numerical Simulation? *(Invited)*

J.A.Hernández & J.Jiménez *Dept. Fluid Mech., Aeronautics, U.P. Madrid, Spain*
Linear and nonlinear instabilities in dense fluidised beds

L. Kleiser & R. Zores *DLR, Göttingen, Germany*
Low resolution simulation on transition and turbulence in channels

M. Lesieur, P.Compte, C.Flores, M.A.Gonze, X.Normand, A.Silveira & S.Yanase *Inst. Méchanique, Grenoble, France*
Three dimensional numerical simulations of coherent stuctures in shear flows

O. Metais *Inst. Méchanique, Grenoble, France*
Anomalous behaviour of a passive scalar convected by isotropic turbulence

J-P. Rivet *Observatoire de Nice, France*
Low viscosity lattice gases: first results

Wednesday, July 11

9.00-13.00 SHEAR FLOWS: II
Chairman: *Lumley*

A. Roshko *Aeronautics, Caltech, Pasadena, Ca. USA*
The mixing transition in free shear flows. *(Invited)*

H. Fiedler *Hermann-Fottinger Inst., T.U. Berlin, Germany*
Control of Turbulent Shear Flows via stationary boundary conditions

M. Jensen *Nordita U., Copenhagen, Denmark*
Kolmogorov Spectra and Structure Functions in Models for Turbulence

M. Landahl *Astronautics and Aeronautics, MIT, Cambridge, Ma. USA*
A New Model for Sublayer Streaks

J.C. Lasheras, A.Lecuona & P.Rodríguez *Mech. Eng., USC, Los Angeles, Ca. USA*
Topology of the vorticity field in 3-D coflowing forced jets

W. Reynolds & P. Juvet *Mechanical Eng., Stanford U., Ca. USA*
Control of organized structures in jets at high Reynolds numbers

I. Wygnanski, Y.Katz & E.Horev *Dept. Engineering, Tel-Aviv University, Israel*
The turbulent wall jet- Some novel measurements and ideas

16.00-18.15 DYNAMICAL SYSTEMS AND TURBULENCE
Chairman: *Liñán*

C. Simo *Dept. Matemáticas Aplicadas, U. Barcelona, Spain*
Hamiltonian Chaos *(Invited)*

T. Bohr *Niels Bohr Institute, Copenhagen, Denmark*
Turbulent coupled map lattices

R. MacKay *Mathematics Inst., U. Warwick, U.K.*
Prediction of turbulent burst velocities for some simple flows

G.Berkooz, P.Holmes & J.L. Lumley *Mech. and Aerospace Eng., Cornell U., Ithaca. NY. USA*
Control of boundary layer and dynamical systems theory: an update

18.30-19.15 PANEL: DIRECT NUMERICAL SIMULATION OR EXPERIMENTS?

A. Roshko *(Moderator)* *Aeronautics, Caltech, Pasadena, Ca. USA*
L. Kleiser *DLR, Göttingen, Germany*
P. Moin *Mechanical Eng., Stanford U., Ca. USA*

Thursday, July 12

9.30-12.00 VORTICITY DYNAMICS
Chairman: *Kleiser*

P. Saffman *Applied Mathematics, Caltech, Pasadena, Ca. USA*
The role of vortex dynamics in turbulent structure. *(Invited)*

H.K.Moffat & R. Ricca *Dept. AMTP, Cambridge Univ., U.K.*
Interpretation invariants of the Betchov- da Rios and of the Euler equations

A. Pumir *Phys. Statistique, ENS, Paris, France*
Stretching and Reconnection of Vortex Tubes

N. Zabusky, R.Pelz & O.Boratav *Mech. and Aerospace Eng., Rutgers U., NJ. USA*
Vortex scattering: Collapse and reconnection of orthogonally offset vortex tubes

12:15-13:00 PANEL: WHAT ARE TURBULENT PUFFS?

C. Van Atta *(Moderator)* *Dept. AMES, UC San Diego, Ca. USA*
Y. Pomeau *Phys. Statistique, ENS, Paris, France*
I. Wygnansky *Dept. Engineering, Tel-Aviv University, Israel*

13:30- CONFERENCE BANQUET AND TOUR

Friday, July 13

9.30-12.45 PATTERN SELECTION MECHANISMS IN TRANSITION, I
Chairman: *Velarde*

G. Ahlers *Dept. Physics, UC Santa Barbara, Ca. USA*
The role of fluctuations near bifurcations in pattern forming systems

H.R. Brand *Dept. Physics, University of Essen, Germany*
Localized states in phase dynamics

J.M. Massaguer *E.T.S.I.Telecomunicación, U.P. Cataluña, Barcelona, Spain*
Shear type instabilities in the Benard problem

C. Pérez García *Dept. Física, U.A. Barcelona, Spain*
Amplitude Equations in Hexagonal Patterns

D. Walgraef *Chimie-Physique, U.L. de Bruxelles, Belgium*
Pattern selection and external fields

S. Zaleski *Ecole Normale Supérieure, Paris, France*
Thermal convection in sheared layers

16.00-17.30 PATTERN SELECTION MECHANISMS, II
Chairman: *Massaguer*

P. Clavin *Université de Provence, Marseille, France*
Turbulent flames and noise generation

R.J. Deissler *CNLS, Los Alamos, NM, USA*
Slugs and Noise Substained Structures

W. Zimmerman *Inst. Festkörperf., Jülich, Germany*
Travelling waves and Turbulent nuclei in EHD convection

17.45-18.45 PANEL: IS THIS THE THEORY FOR THESE EXPERIMENTS?

W. Reynolds *(Moderator)* *Mechanical Eng., Stanford U., Ca. USA*
J.L.Lumley *Mechanical Aerospace Eng., Cornell, USA*
P.G. Saffman *Applied Mathematics, Caltech, Pasadena, Ca. USA*
...and everybody else.

18.45-18.46 CLOSING REMARKS

Saturday, July 14

POST-CONFERENCE TOURS (?)

Abstracts

Transition to Chaos in Nonlinear Oscillators

J.C. Antoranz

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We have studied the different intermittent regimes in a nonlinear quadratic oscillator. By means of analog electronic simulations the intermittency region has been located in parameter space. The power spectrum exhibits a $1/f^{\alpha}$ behaviour, with $\alpha = 1.2$. We have numerically studied the intermittent region and two different bifurcation schemes leading to Pomeau-Manneville intermittencies type-I and -III have been identified. Furthermore a continuous change in the slope of the power-law low-frequency power spectrum has been found and interpreted in terms of competition between two unstable fixed points. Finally a onedimensional map (a seventh degree polynomial iterative map) which displays the whole phenomenology of the physical system is provided. A soft transition between type-I and -III intermittencies is found in that iterative map. Characterisation of the dynamics is accomplished by studying the critical lines in parameter space and statistical measurements such as Lyapunov exponents, distribution of laminar periods end low-frequency power spectra.

LOCALIZED STATES IN PHASE DYNAMICS

Helmut R. Brand

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and
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Los Alamos, NM 87545, USA.

Recently two groups have described the observation of confined states in an annulus near the onset of convection in binary fluid mixtures. These confined states are characterised by the fact that for part of the annulus a convective pattern is visible -that is the envelope of the convective pattern assumes a finite value- whereas the rest of the container is in the heat conduction state. These observations are now under intense investigation theoretically and experimentally. Here we discuss the analogous phenomenon in phase dynamics, namely the coexistence of two patterns showing different wavelengths in different parts of the cell, a concept we have introduced recently. The concept of phase dynamics, the analogue of hydrodynamics for large aspect ratio pattern-forming nonequilibrium systems, has not only found experimental verification early on, but its usefulness far above onset of the instability has also been demonstrated recently experimentally. The analogue of hydrodynamic variables are the phase variables, whose slow spatial and temporal variations characterise the changes of the wavelength of the pattern as a function of space and time. We elucidate that confined states in phase dynamics are an intrinsically nonlinear phenomenon and we discuss the physical properties of these novel states. We critically compare our predictions with recent experimental results on slot convection (the height of the cell is larger than the width) in a simple fluid and on the Taylor instability for the flow in the gap between co-rotating cylinders and we suggest further experiments. We show that for a stationary pattern the phase variation and the local wavevector satisfy a conservation law and we discuss similarities and differences with the corresponding equations for a propagating pattern. We also point out that a generalised thermodynamic potential can be found for the equations associated with the phase variations and the local wavevector of a stationary 1D pattern.

Control of the turbulent boundary layer and dynamical systems theory: an update

Gal Berkooz,
Philip Holmes, John Lumley

Cornell University
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ABSTRACT

We expand the velocity field in the vicinity of the wall in empirical eigenfunctions obtained from experiment. Truncating our system, and using Galerkin projection, we obtain a closed set of non-linear ordinary differential equations with ten degrees of freedom. We find a rich dynamical behavior, including in particular a heteroclinic attracting orbit giving rise to intermittency. The intermittent jump from one attracting point to the other resembles in many respects the bursts observed in experiments. Specifically, the time between jumps, and the duration of the jumps, is approximately that observed in a burst; the jump begins with the formation of a narrowed and intensified updraft, like the ejection phase of a burst, and is followed by a gentle, diffuse downdraft, like the sweep phase of a burst. The magnitude of the Reynolds stress spike produced during a burst is limited by our truncation. The behavior is quite robust, much of it being due to the symmetries present (Aubry's group has examined dimensions up to 128 with persistence of the global behavior). We have examined eigenvalues and coefficients obtained from experiment, and from exact simulation, which differ in magnitude. Similar behavior is obtained in both cases; in the latter case, the heteroclinic orbits connect limit cycles instead of fixed points, corresponding to cross-stream waving of the streamwise rolls. The bifurcation diagram remains structurally similar, but somewhat distorted. The role of the pressure term is made clear - it triggers the intermittent jumps, which otherwise would occur at longer and longer intervals, as the system trajectory is attracted closer and closer to the heteroclinic cycle. The pressure term results in the jumps occurring at essentially random times, and the magnitude of the signal determines the average timing. Stretching of the wall region shows that the model is consistent with observations of polymer drag reduction. Change of the third order coefficients, corresponding to acceleration or deceleration of the mean flow, changes the heteroclinic cycles from attracting to repelling, increasing or decreasing the stability, in agreement with observations. The existence of fixed points is an artifact introduced by the projection; however, a decoupled model still displays the rich dynamics. It can be shown that the class of systems having no streamwise variation are an optimal model of streamwise averaged dynamics. Feeding back eigenfunctions with the proper phase can delay the bursting, (the heteroclinic jump to the other fixed point), decreasing the drag. It is also possible to speed up the bursting, increasing mixing to control separation. We show that the empirical eigenfunction basis is optimal for short time tracking in control applications.

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TURBULENT COUPLED MAP LATTICES

Tomas Bohr

The Niels Bohr Institute University of Copenhagen Denmark

We shall discuss the modelling of turbulent systems by coupled map lattices. The constituent maps can either have chaotic attractors (or repellors) or be completely non-chaotic. We give examples illustrating chemical turbulence, chaotic interface growth and anomalous ordering processes.

Spatiotemporal intermittency in the one-dimensional complex Ginzburg-Landau equation.

Hugues Chaté and Paul Manneville
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F 91191 Gif-sur Yvette, France.

We present a survey of a systematic study of the spatiotemporally disordered regimes of the complex Ginzburg-Landau equation in one dimension in the large size limit. The problem of defining phases and transitions between them is addressed and discussed within the more general framework spatially of extended dynamical systems.

LOCALIZED STRUCTURES
GENERATED BY SUBCRITICAL INSTABILITIES

S. Fauve

Laboratoire de Physique de l'ENS Lyon

Localized structures are widely observed in fluid flows. Well known examples are the local regions of turbulent motion surrounded by lamir ır flow, which develop in many open-flow experiments. More recently, spatially localized standing waves have been observed on a horizontal layer of fluid submitted to vertical vibrations, and convection in binary fluid mixtures displayed localized traveling waves. In all cases the possible origin of localized structures lies in the existence of a subcritical instability, that implies that two stable homogeneous states coexist in an interval range of the control parameter. The localized structure then consists of a small region in the bifurcated state surrounded by the basic state. When there exists a free energy to minimize, this structure is not stable, it shrinks or expands. We have shown in the case of a subcritical Hopf bifurcation that the stability of the localized structure is a non-variational effect that traces back to the coupling between the phase and the amplitude of the wave complex amplitude. In slighty dissipative systems, the localized structure can be computed perturbatively ; the leading order effect of dissipative terms is just to select the size of the structure among a family of scale invariant solitons. We show how these non-variational effects occur in different experimental situations.

SPECTRAL STUDIES OF TRANSITION IN TWO AND THREE DIMENSIONAL SHEAR LAYERS

M. Gharib, M. Beizaie and D. Liepmann

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Evolution of two-dimensional vortical structures was studied in a soap-film jet device. The onset of transition to a random state (2-D turbulence) was compared to a similar transition in an axi-symmetric jet. It was shown that for 2-D case, the roll-up process steepens the slope of the energy spectrum until it reaches K^{-4}. The process of pairing or appearance of small structures results in shallower slopes for the energy spectrum. In the two-dimensional transition, unlike the three-dimensional shear flows, small scale turbulence appears only in the core region of vortical structures. These fine structures which are concentrated inside the vortex core survive the amalgamation processes among vortices. The spectral studies indicate that unlike three-dimensional transition, the appearance of fine scale structure in the core region support the coherence of the vortical structures and therefore prolongs their lifetime.

Linear and nonlinear instabilities in dense fluidised beds[1]

Juan A. Hernández
Javier Jiménez
School of Aeronautics
Universidad Politécnica, Madrid (Spain)

Fluidised beds, in which a dense powder is supported by an upward moving stream of gas, are known to become unstable for certain values of relative velocity and mass fraction. Experimentally, three types of behaviour are known: Slug flow, in which the bed fractures into transverse bands of high powder concentration, separated by empty regions; Bubbles, in which the gas passes through the bed in the form of relatively large rising bubbles; and, more rarely, streamwise channelling of the gas stream through the powder bed. The mechanisms and possible relationships between these three patterns are not well understood.

That problem is studied here by means of linear stability analysis and of a fully nonlinear spectral numerical simulation of a two fluid model for the bed. Two primary instabilities are identified, as well as a secondary one, all of which depend on the viscous interaction between phases. The first one is responsible for the fracture of the bed into transversal slugs, and is due to the interaction of the volumetric coupling between phases with the inter-phase friction. The leading edge fronts of these slugs are then subject to a secondary, two dimensional instability which deforms them, resulting in the formation of bubbles. The mode of action of this second instability is somewhat similar to that of Rayleigh Taylor, but its origin is also in the viscous interaction between phases. Finally, for some ranges of parameters, the uniform bed may also become unstable to a transverse mode that results in the formation of longitudinal channels, and which depends on the variation with mass fraction and inter-phase velocity of the particle "pressure" of the cloud. When this mode is active, but weaker than the slug forming instability, the bed breaks first into bubbles which then coalesce into longitudinal channels.

All these mechanisms are different from a fourth one, that had been proposed by other investigators, and which depends on the interaction of volumetric coupling and buoyancy forces. This latter mechanism was also identified but found to be unimportant for these flows.

Examples of the temporal evolution of slightly perturbed initial fields into the bubble and channel states are given, and the relevant parameter ranges are identified. Some consideration is also given to the effects of initial conditions on the results of the competition between different unstable modes.

[1]Supported by Spain-US Technological Cooperation Committee

Interaction of Turbulent Wake and Internal Gravity Waves

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The internal gravity waves and the turbulent wake of a sphere moving through stratified fluid were studied experimentally by the fluorescent dye technique. The Reynolds number Re= U.2a/v was, when possible, kept constant at 3.10^3 and the Froude F= U/aN ranged from 0.5 to 12.5 . Here, U is the displacement velocity of the sphere, a its radius and N the Brunt-Väisälä frequency of the linearly stratified fluid.

First we show the wake structure in homogeneous fluid (F=0) which serves as a reference case. In particular, the Strouhal number of the helical vortex shedding was determined for Reynolds numbers up to 10^4. In stratified fluid, three flow regimes can be be distinguished according to $F < 1$, $1 < F < 4$ and $F > 4$. When $F < 1$ flow separation is strongly influenced or completely suppressed by the pressure field of the lee waves and when $F < 0.4$ the wake is nearly two- dimensional; at low Reynolds numbers the results are in good agreement with the numerical simulations of Hanazaki (1988). For larger values of F the wake is modulated by the lee waves. When $F > 4$ the near wake is identical to the homogeneous case and wake collapse occurs further downstream. The nondimensional times Nt which characterise the evolution of the wake are as follows: Nt = 2, stratification becomes first effective; Nt =14, wake collapse is completed at all scales; $Nt > 20$, the wake is quasi-twodimensional.

Concerning the internal wave field, the most striking result is the observed transition from a lee wave regime in the wake of the sphere to random internal gravity waves generated by the coherent structures in the wake. This transition occurs at about F= 4 . The lee waves are well described by linear theory of moving point sources in a stratified fluid (Lighthill, 1978). The gravity waves emitted by the turbulent wake have a dominant wave length of about about 4.d, which is about the scale of the helical vortex structures.

Hanazaki, H. 1988. A numerical study of three-dimensional stratified flow past a sphere. J. Fluid Mech. 192, 393-419.
Lighthill, J. 1987. Waves in fluids. Cambridge University Press.

Amplitude equations and Stability

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The use of simplified nonlinear evolution models such as the Ginzburg-Landau equation has become fairly widespread in the study of hydrodynamic instabilities.Their relative simplicity has provided a convenient framework for the identification of the various selection mechanisms governing the dynamics of spatio-temporal patterns.This presentation will focus on several examples of application to open free shear flows such as wakes,jets and mixing-layers.

Typically,one has tc choose between two distinct strategies:the model is either derived by asymptotic means from the fundamental equations of motion or it is a priori postulated from symmetry properties and phenomenological considerations.These two roads will be illustrated here.First,it will be shown that the implementation of asymptotic techniques leads to a consistent description of two-dimensional global modes in spatially-developing flows such as wakes and hot jets.The Ginzburg-Landau equation then arises "naturally and it plays a central role in the frequency selection mechanism.In the second example,a phenomenological model of defects dynamics in three-dimensional free shear layers and wakes will be postulated to explain qualitatively recent experimental observations by Browand.The model will demonstrate in particular that local pairing first takes place at the defect cores and then spreads out as a bubble in the surrounding unpaired patterns.This feature appears to be in qualitative agreement with experimental findings.

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Transitional behaviour of non-symmetric amplitude equations

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Transition to chaos in two dimensional Poiseuille flow has been shown to be mediated by the formation of isolated permanent packets of nonlinear Tollmien-Schlichting waves, and by their splitting and coalescence. This behaviour is reminiscent of that of the turbulent "puffs" observed in circular pipes.

On the other hand, recent evidence has been presented of the formation of stable solitary solutions of a modified Ginzburg-Landau amplitude equation, and it is known that the weakly nonlinear behaviour of T-S waves in plane Poiseuille flow satisfies the Ginzburg Landau equation. This suggests that both phenomena might be related. However the solitary packets in the plane channel are quite different from those in the G-L equation. No splitting or coalescence is observed in the latter, and their spatial shape is symmetric to back to fore reflection.

A more similar behaviour can be obtained if terms containing odd derivatives are added to the G-L equation. There are two possible choices, if the G-L equation is considered as the result of a perturbation expansion. Both are explored numerically and seen to result in different modifications of the solution. In both cases, the solitary waves are non-symmetric, more in accordance with those observed in the channel. One of the choices ($\partial^3 A/\partial x^3$) results in solitary wave splitting and interaction. The other one ($|A|^2\partial A/\partial x$) has the effect of making the uniform nonlinear equilibrium state unstable. In some cases it is possible to have non-uniforn stable solutions for supercritical, as well as for subcritical situations, but they take the form of modulated wavetrains, instead of solitary packets.

Low-Resolution Simulations of Transition and Turbulence in Channels

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Direct numerical simulations of the complete laminar-turbulent transition process and fully developed turbulence have recently become feasible for incompressible flows in simple geometries and at low Reynolds numbers (see e.g. [1,2,3]). Such simulations require a very high numerical resolution. On the other hand, in its initial stage transition is well described by a small number of modes of the usually employed spectral discretization in space. Although such coarse-grid simulations of transition are not reliable, they can often be continued into a "chaotic" state without becoming numerically unstable. The statistical results in the chaotic state are sometimes [4,5] surprisingly close to well-resolved turbulent flows.

In the present contribution we report on further numerical experiments with severe truncations for transitional and turbulent channel flow in the Reynolds number range of 1000-5000 (based on channel half-width and laminar centerline velocity). The numerical results have been evaluated by comparison with high resolution simulations and experimental data. In the initial stage well before the appearance of the "spikes", transition is accurately represented by the low resolution model. In the later phases irregular fluctuations occur earlier and their amplitudes are significantly larger than in fully resolved simulations. Statistical data for the turbulent state are obtained by averaging over wall-parallel planes and a long time interval (2000 dimensionless time units). It is found that global quantities, such as the mean centerline velocity and wall shear stress, are quite close to the experimental data. For the Reynolds number of 2777 the number of the modes was systematically reduced. A "turbulent" channel flow could be maintained down to a resolution of only 4-6 points (2-3 Fourier modes) in the horizontal directions and 17 Chebyshev modes in the normal direction. Taking into account the restrictions by the continuity equation, boundary conditions and symmetry assumptions, this system contains less than 350 independent real degrees of freedom.

References

[1] Kim, J., Moin, P. Moser, R.: Turbulent statistics in fully developed channel flow at low Reynolds numbers. JFM 177 (1987), 133-166

[2] Gilbert, N., Kleiser,L.: Near-wall phenomena in transition to turbulence. In *Near Wall Turbulence: 1988 Zoran Zaric Memorial Conference*, ed. S.J. Kline & N.H. Afgan, Hemisphere, Washington, D.C. (1990), pp. 7-27

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[5] Gilbert, N., Kleiser,L.: Subcritical transition to turbulence in channel flow, in *Direct and Large Eddy Simulation of Turbulence*, ed. U. Schumann & R. Friedrich, Vieweg, Braunschweig (1986), pp. 1-18

Topology of the vorticity field in three-dimensional coflowing forced jets

Juan Lasheras

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Antonio Lecuona and Pedro Rodríguez

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We examine the near field structure of vortex patterns and the dynamics of their interaction in laminar ($Re = 10^3$) and the transitional ($Re = 8.10^3$) coflowing jets under the single or combined effect of axial and azimuthal forcing. The inner high velocity jet is axially forced by acoustic means while the azimuthal forcing is introduced by modifying the exit lip of the jet's nozzle either to achieve a corrugated or an indented shape. It is demonstrated that the dynamics of the three-dimensional vortex structure resulting from this forcing leads to a large variety of entrainment and mixing patterns. It is shown that for each azimuthal forcing, and for a fixed velocity ration between the inner and outer jet, there exists a critical Strouhal number for which a symmetric instability mode leads to a pattern of lateral ejections of closed vortex loops. Furthermore, we show the existence of a second symmetric mode developing at a higher Strouhal number consisting of double number of lateral ejections. The observed three-dimensional vortex patterns and their topological changes are interpreted in terms of three-dimensional inviscid instability of the two concentric cylindrical vorticity layers of opposite sign emanating from the jet nozzle.

THREE-DIMENSIONAL NUMERICAL SIMULATIONS OF COHERENT STRUCTURES IN SHEAR FLOWS

by

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To be presented at the NATO A.R. Workshop on the global geometry of turbulence Rotta, Spain, 8-14 July 1990

We investigate, with the aid of three-dimensional direct-numerical simulations, the origin and dynamics of coherent structures in the following flows: incompressible periodic mixing layers and wakes, mixing layer behind a backwards-facing step, and compressible boundary-layer developing on a flat plate (low Mach number).

In the mixing-layer case, the calculation is done using pseudo-spectral methods. The basic velocity field is a hyperbolic-tangent profile $U \tanh 2y/\delta_i$, with a Reynolds number $U\delta_i/\nu = 100$. The initial velocity field is the basic velocity, above which we have superposed two small random perturbations of wide spectrum peaking at the fundamental mode: a three-dimensional one, of kinetic energy $\epsilon_{3D}\ U^2$ and a two-dimensional one, of kinetic energy $\epsilon_{2D}\ U^2$. A passive-scalar transport equation is solved as well, of same initial profile as the basic velocity profile. Iso-surfaces of the passive scalar and the three vorticity components are visualized, as well as the vortex lines. According to the value of the initial three-dimensionality rate $r = \epsilon_{3D}/\epsilon_{2D}$, three regimes are found: for $r = 0.01$, two-dimensional large coherent Kelvin-Helmholtz billows are formed. For $r = 0.1$, the billows slightly oscillate in phase, as in the translative instability proposed by Pierrehumbert and Widnall (1982). The vortex lines plots show also in this case the presence of longitudinal vortices (carrying a vorticity of the order of one tenth of the initial vorticity) stretched between the big rollers. They might originate from vortex lines oscillating about the stagnation line, as proposed by Lasheras and Choi (1988). For $r = \infty$, the fundamental billows which appear have strong spanwise oscillations which are not in phase. Pairings between the primary vortices exhibit the same spanwise decorrelation, and reconnections of the billows occur, giving rise to Λ-vortices staggered in the streamwise direction. The same structure has been found by Sandham and Reynolds (1990) in the compressible case.

The same numerical code has been used for a gaussian wake. In the case of a quasi-two-dimensional perturbation, the coherent structures consist in a Karman street, with again longitudinal vortices stretched between the billows of opposite sign, in agreement with the findings of Meiburg and Lasheras (1988).

A solid rotation has been further imposed in the spanwise direction. This is important for oceanic applications for instance, in order to study the stabilizing effect of the Coriolis force with respect to three-dimensional perturbations of barotropic eddies. In the mixing-layer case (with $r = \infty$), calculations at an initial Rossby number $R_O = 0.25$ show a stabilizing effect of rotation both for cyclonic and anticyclonic eddies, in good agreement with Proudman-Taylor theorem. For $R_O = 5$, the anticyclonic mixing layer is quickly destabilized, whereas the Kelvin-Helmholtz vortices are strongly two-dimensionalized in the cyclonic case. This is confirmed by calculations done on the rotating wake, and agrees with experiments performed by Tritton and Davies (1985) on rotating mixing layers, and by Chabert d'Hières et al. (1988) on a wake. This result might be interpreted by the fact that in the rotating case, the absolute vortex filaments are material lines.

Furthermore, we have looked at an unforced (non rotating) spatially-growing mixing layer behind a backwards-facing step, using conservative finite-volume methods. The vorticity and pressure contours show quasi-two-dimensional Kelvin-Helmholtz billows shed behind the step: as in the above quasi-two-dimensional periodic mixing layer ($r = 0.1$), weak longitudinal vortices of alternate sign are stretched, and seem to merge downstream, where the big rollers pair. This is in agreement with the experimental measurements of Huang and Ho (1990) in a mixing layer behind a splitter plate.

We have finally investigated the dynamics of vortex filaments in a compressible boundary layer developing above a flat plate, at a Mach number of 0.5. The initial field is a set of compressible Tollmien-Schlichting waves generated through a two-dimensional calculation, which is perturbed by a random three-dimensional perturbation. The calculation shows the deformation of the vortex filaments into hairpin-shaped vortices. With the aid of a subgrid-scale model based on the local velocity structure function developed by Métais and Lesieur (1990), we are able to follow the whole transitional stage up to the breakdown into developed turbulence. Detailed results concerning the mean velocities and Reynolds stresses will be presented during the workshop.

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Shear type instabilities in the Benard problem

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Turbulence produced in closed containers by drivings other than stirring have often been considered non-genuine or, at least, as being qualitatively different from turbulence in open flows. Thermal convection and Couette flows, for instance, can provide examples of such a turbulent attractors. But this need not be the case in those regions of parameter space where shear type instabilities are dominant. Thermal convection in low Prandtl number fluids is one such a case, though some others exist.

In the communication we shall examine numerical results from a truncated model of thermal convection devised so as to be dominated by a shear type instability. The physical mechanism in this model strongly recalls that producing axial flow along a bent filament. As a signature of this three-dimensional dynamics, the flow displays a large activity in terms of vertical vorticity or, its counterpart, helicity. It is, precisely, such a lack of reflexional symmetry the main ingredient for the whole dynamics.

The numerical results show several chaotic behaviours, depending on technical details, but all them being asociated with global instabilities -i.e. homoclinic explosions. These results may serve to introduce a discussion about the possibility of producing different chaotic pictures of the same experiment by simply changing the variable to be measured. Temperature or heat flux, for instance, may behave as highly averaged magnitudes in that respect, but velocity or vorticity, do not.

INTERPRETATION OF THE INVARIANTS OF THE BETCHOV-DA RIOS EQUATIONS AND OF THE EULER EQUATIONS

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In the context of the localized induction approximation for the motion of an inextensible vortex line in a perfect fluid flow, we interpret certain conserved quantities that emerge from the Betchov-Da Rios equations as energetic invariants, and we employ the recurrence formula to calculate the set of so-called "conservation laws" as constants of motion for the related Non Linear Schrödinger Equation (NLSE). In the context of the Euler equations, given that the topology of the vortex structure is conserved and the helicity invariant is the natural measure of the topological complexity of the field, we underline the role that this invariant can have in taking account of such complexity. Furthermore, by the association of an 'energy spectrum' with any knot or link present in the fluid, the lowest ground-state energy is interpreted as an even more powerful invariant for evaluating the knot or link complexity of the field structure.

Some examples of what can be learned using direct numerical simulation of turbulence

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This presentation is divided into three parts. First a brief review of the technique of direct numerical simulation and its usage for the study of turbulence physics and modeling will be described. Examples are selected from studies where new knowledge has been gained largely due to the unique capabilities of the direct simulation. These include elucidation of the nature of organized structures in wall bounded flows, and the apparent universality of structures in shear flows.

In the second part, new advances in the numerical methodology for simulation of complex flows will be described. It is shown that high order finite-difference techniques are sufficiently accurate for simulation of turbulent flows with grid resolution comparable to that for spectral methods. Computation of complex flows require "turbulent" inflow and outflow boundary conditions. The inflow velocity boundary conditions are generated using a prescribed temporal and spatial energy spectrum and random phase distribution. Application of this method to the entry flow in a channel indicate that approximately 20 channel widths in the downstream direction are required for turbulence to reach equilibrium. In both spatial and temporally evolving isotropic turbulence, the time required for the non-linear effects to settle is about $0.25l/u'$, where l/u' is the initial large eddy turn-over time. Excellent agreement is obtained between the spatially evolving isotropic turbulent flow downstream of a grid with the comparable spatially periodic simulation. In the simulations of compressible decaying isotropic turbulence it is shown that local eddy shocklets form with rms fluctuation Mach number as low as 0.3 with no initial density fluctuations. Other examples of simulations of spatially evolving flows that will be presented are the shock/turbulence interaction problem and the transition to turbulence in a flat plate boundary layer. In the former example it is shown that the turbulence fluctuations' pressure work term leads to an unexpected behavior of turbulent kinetic energy immediately downstream of the shock.

Finally, some novel experiments using direct numerical simulations that would be difficult or impossible to perform in the laboratory will be described. The primary example is the isolation of the minimal turbulence flow unit near the wall, and its application to the study of the flow over ribblets, three-dimensional boundary layers, and active control of wall-bounded turbulent flows.

DYNAMICS OF LARGE SCALE STRUCTURES IN TURBULENT TWO DIMENSIONAL WAKES

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Abstract

The present experimental work was initiated with the purpose of addressing certain questions regarding the origin and evolution of large scale vortical ctructures in a turbulent wake, as they interact with its mean shear flow field. The main question under investigation has been that of turbulence memory of initial flow conditions, due to the vortical structures formed at the starting stage of flow development. However, the obtained information revealed some interesting aspects regarding the dynamical behaviour of these structures, pertaining to phenomena such as vortex generation, decay and pairing of vortices, which are also discussed in the present work.

The role of large scale vortices as carriers of turbulence memory of initial flow conditions in turbulent wakes is dominently related to the development of the flow towards a state of self preservation and similarity. This question has been addressed by a number of investigators and presently there are two different views, briefly discussed in the following.

Townsend's "equilibrium hypothesis" states that the general structure of turbulence in all self preserving flows is the same, implying that the structure of these flows shows no memory of initial flow conditions. This, according to Bevilaqua and Lykoudis, is not consistent with the results of experiments demonstrating, that vortices formed at the initial stage of flow development persist into the region of self preservation. To support their views, they performed a series of experiments in which the turbulent wakes of a sphere and a porous disk, were compared. They found that owing to the inital condition differences, two distinct self-preserving states with differences in the large vortex structure evolved and condluded, that coutrary to the implication of Townsend's hypothesis, there exist a turbulence memory caused by persisting

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vortices shed at the flow origin.

The mentioned experiments cover a downstream distance of approximately 100 diameters and the principal remaining question is, what happens far downstream, that is, does the turbulence memory fade in the far wake or it continues to persist?

The conducted in the present work visualization experiments, in which the structure of the turbulent wakes formed behind a solid cylinder and a porous plate, offer a qualitative answer to the above question. They also offer some insight, regarding the dynamics of large scale structures, especially in the far wake.

Regarding the question of turbulence memory the present experiments have shown that vortices shed behind the cylinder persist for probably a few hundred diameters downstream influencing therefore the turbulent flow structure. Beyond this distance, their destruction results to the fading of turbulence memory of initial conditions, as the visually indentical structure of the two wakes indicates. It appears however, that the growth-decay cycle of vortical structures, suggested by Townsend is also present in this region while it dominates the flow after the obliteration of the initial vortices. Also, apart from the decicive role of the initially shed vortices in the development of the wake towards self preservation, they also dominate the entrainment processes causing its broadening.

As already mentiomed, certain phenomena pertaining to the dynamics of large scale vortices in turbulent shear flows have been identified to occur in both wakes. Of particular interest is the obtained evidence of the existence of different modes of vortex generation in a turbulent wake. Apart from the flow instability vortex generation mode, vortex generation has been observed to occur in the very far wake, in the stretching field created between two adjacent vortices. This mode involves the appearence of a "line" of elementary adjacent vortices in the mentioned location, which subsequently grow by a process of coallessing.

Finally in the light of the present experiments, current experimental techniques for studying large scale structures are discussed.

Amplitude Equations in Hexagonal Patterns

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ABSTRACT

The transition between hexagons and rolls in convective patterns have been studied. The transition thresholds and changes in the Nusselt number are discussed theoretically in terms of calculation made by Busse (1967a) and with amplitude equations. Experiments have been made in a shallow layer of pure water under non-Boussinesq conditions by means of three complementary techniques: shadowgraphic (qualitative), optical (based on the deflections of a laser beam) and a calorimetric. The experimental values of the critical Rayleigh number R_c and the critical wavenumber k_c are in agreement with theoretical ones. However, theory and experiments show some discrepancies in the slopes of the Nusselt number as function of the heating and in the thresholds of the hysteretic hexagons-rolls transition. These discrepancies are discussed in terms of lateral effects and of the presence of defects in the pattern.

CONTRIBUTION OF J.P. RIVET TO THE NATO ARW

ON "THE GLOBAL GEOMETRY OF TURBULENCE".

Low viscosity lattice gases: first results.

We present some numerical results in fluid dynamics, obtained with the 3D lattice gas model called "FCHC-8". This model is based on the FCHC lattice with collision rules that violate the semi-detailed balance and the particle-hole symmetry. This model has a viscosity that was predicted to be negative under the Boltzmann approximation, but that revealed to remain positive in direct numerical measures.

After a brief description of the model, we present the numerical experiments that were performed to measure the viscosity, the Gallilean factor and the sound velocity of that model. The results are compared with similar results obtained on a 3D non-violating lattice gas model (FCHC-3).

We also present preliminary simulations and visualisations of 2D and 3D flow past cylinders and flat plates. The goal is to understand the mechanism by wich such flow become fully 3D by symmetry-breaking.

Control of Organized Structures in Jets at High Reynolds Numbers

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At low Reynolds numbers, acoustic disturbances can be used to change the structure of jet flows dramatically. By judicious combination of streamwise and helical modes, the entrainment, spreading rate, and mixing of a round jet can be very substantially increased through creation of a "blooming jet". In earlier work we showed that blooming can be extended to jets with turbulent lip boundary layers at jet Reynolds numbers at least as great as 100,000 and Mach numbers of at least 0.3. However, at high Reynolds numbers the required excitation amplitude is very large because the very thin initial shear layer is only weakly receptive to the relatively low frequencies desired by the jet for blooming.

The idea of the present work was to study the enhancement of the controllability of the jet through thickening of the nozzle boundary layer and hence the initial free shear layer. This reduces the frequency most rapidly amplified by the initial shear layer, and makes it easier to control the jet with weak forcing. Three approaches to shear layer thickness control have been explored; 1) slight diffusion (adverse pressure gradient) near the jet exit; 2) streamwise blowing near the net exit; and 3) wall roughening near the jet exit. Quantitative data and flow visualization pictures will be presented to show the relative promise of these three methods for control. In particular, a slight diffusion near the exit has proven extremely effective in enhancing the receptivity of the shear layer, and may offer a way to bring this technology of jet mixing enhancement and control to bear in practical situations.

Modelling and control of Karman vortex streets

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Differential equations are constructed from special flow vector fields obtained from experimental time series of Karman vortex streets. It will be shown that the velocity signal measured in the regular range ($50 < Re < 150$) of a vortex street can be modelled by a second order differential equation (ODE) with 10 parameters. The parameters are nearly independent of the probe position and of the Reynolds number. Discontinuities in the Strouhal-Reynolds number dependance (e.g. the Tritton discontinuity) are also reflected in the coefficients. With the knowledge of the ODE the response of the vortex street on perturbations can be predicted.

Hamiltonian Chaos

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Hamiltonian systems with two or more degrees of freedom are generically non integrable. Then they display some amount of chaos. For integrable systems the phase space is foliated by invariant tori or cylinders which contain the orbits, and the Lyapunov exponents are zero. When an integrable system is perturbed some of those invariant objects are broken and chaotic regions appear. For analytical systems and small values of the perturbation parameter these chaotic regions are very small. Most of the invariant tori subsist and the chaotic regions seem to be dense. They are non connected for two degrees of freedom and, due to Arnold's diffusion, they are probably connected for three or more degrees of freedom. Both the chaotic zones and the break down of the invariant tori are related to the existence of homoclinic and heteroclinic tangles. A survey of results and an outlook is presented.

Abstract prepared for NATO Advanced Research Workshop on THE GLOBAL GEOMETRY OF TURBULENCE, Impact of Nonlinear Dynamics, Rota , Spain , July 8-14, 1990

FLUID DYNAMICAL CHAOS IN VORTEX WAKES

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abstract

Recent experiments show that temporal chaos and quasiperiodicity in vortex shedding laminar wake flows behind stationary and oscillating two-and three dimensional cylindrical and airfoil shapes is produced by competing vortex shedding modes . These observations may provide some clues as to how one might extend dynamical systems concepts to real fluid turbulence. The observed temporal chaos is produced by coherent large scale vorticity patterns produced by the collective interaction of arrays of concentrated vortices due to the effects of vortex stretching , tilting, splitting, dislocation, and reconnection. In an idealized sense the temporal chaos is caused by certain solutions to the requirements that the collective interactions of the vorticity field must satisfy the classical vorticity conservation laws of Helmholtz and the Biot-Savart law. The "mode competition" engendered by these constraints can be caused either by perturbations due to externally-imposed or self-induced forcing of time-unsteady boundary conditions , or by time-independent three-dimensional geometrical variations .In some cases these perturbations effectively cause a spatial modulation of the governing Reynolds number control parameter .

The collective stretching, deformation, dislocations, and reconnections produced in the evolving vortex arrays sometimes arranges them into compact spatial patterns with a scale much larger than individual vortices. The convection of these vortex structures past a fixed probe gives rise to temporal chaos in the velocity field observed by a probe at that point.

These chaotic laminar flows are not turbulent in the usual sense. However, they may constitute a useful paradigm for helping to define and to eventually understand the physics of spatial and temporal chaos in turbulent flows. These observations thus reinforce the recurrent idea that a description of the topology of vorticity fields in fully developed turbulent flows may reveal some essential physical mechanisms and suggest that it may shed some light on how to develop a chaos -like theory for fluid turbulence.

Some current wake experiments on vortex shedding behind tapered cylinders and cones (Piccirillo and Van Atta, in progress) will be discussed in the above context . The apparent quasiperiodicity found in these wakes is found to be directly related to the splitting of vortex lines associated with the variation of shedding frequency with axial location and associated axial cellular structure. These experimental results will be compared with current numerical computations of flow past tapered cylinders being carried out by Jesperson and Leavitt .

THE TURBULENT WALL JET- SOME NOVEL MEASUREMENTS AND IDEAS

by
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The plane, turbulent wall jet, evolving over a flat surface in the absence of an external stream is a generic flow governed by the boundary layer equations. Although this flow was extensively investigated over the years because of its many engineering applications it is still poorly understood. There is a general agreement that the mean velocity in the wall jet is self similar but the parameters scaling it are controversial in-spite of the massive statistical data available in the literature. The complexity of this flow stems from the fact that it's outer part resembles a free jet, while it's inner part resembles a turbulent boundary layer. In fact most models attempting to predict the average characteristics of the turbulent wall jet superimpose a free jet on top of a boundary layer by using strip integrations and matching the most obvious boundary conditions.

Experimental investigations of large coherent structures in turbulent shear flows bypassed the wall jet concentrating either on wall bounded flows like a boundary layer or a channel, or on free shear flows like the mixing layer, the wake and the jet. In the latter category of flows, the large coherent structures were identified as the predominant instability modes and were quantitatively analyzed in this context. The generic wall jet is inviscidly unstable in its outer region and may thus possess large coherent structures characteristic of a plane turbulent jet. The similarity between the outer part of the wall jet and the free jet is explored in this context and the relevance of the solid surface to the evolution of the large coherent structures will be assessed. Although the investigation is mostly experimental, it includes a rudimentary stability analysis in order to quantify the scale and the intensity of the observed large coherent structures. The experiments were carried out in air in the simplest wall jet configuration in the absence of an external stream and surface curvature. Harmonic, two-dimensional excitation was introduced by a flap placed at the lip of the nozzle or by a speaker located in the plenum chamber. The flow was incompressible and the Reynolds Numbers based on the efflux velocity and on the nozzle dimension varied between 3×10^3 and 3×10^4.

Vortex Scattering:
Collapse and Reconnection of Orthogonally-Offset Vortex Tubes [1]

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We investigate by direct numerical simulation the three-dimensional interaction of orthogonally-offset vortex tubes. We discuss, visualize and quantify several generic processes: filamentation or "cascade" in 3d; collapse; vorticity amplification and attenuation resulting from convective processes; and intense dissipative bursts that result from quasi-two-dimensional processes associated with "folding" near critical points.Generalizations to turbulent environments will be made.

[1] Graphics supplied by D. Silver and Z-P Gu of Rutgers Department of Electrical Engineering and CAIP, and C-N Liu , IBM

Thermal Convection in Sheared Layers

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Abstract

Two dimensional numerical simulations of thermal convection with shear are presented. The Boussinesq equations are solved for a horizontal layer of fluid bounded by two rigid plates. Horizontal boundary conditions are periodic. The top plate may have an imposed velocity. This configuration partially reproduces the effect of a laminar wind blowing on boundary layers in thermal turbulence at high Rayleigh number. Numerical experiments at Rayleigh numbers up to 10^6 show that shear reduces the heat flux. The presence of shear also causes a turbulent state to appear. This turbulent state is compared to the one obeserved in experiments.